

THE LUMINOSITY FUNCTION OF QSO HOST GALAXIES

Lutz Wisotzki¹, Björn Kuhlbrodt², Knud Jahnke²

¹*Universität Potsdam, ²Hamburger Sternwarte*

¹lutz@astro.physik.uni-potsdam.de

Abstract We report on results from H band imaging observations of a complete sample of high-luminosity low-redshift QSOs. The luminosity function of QSO hosts is similar in shape to that of normal galaxies, although offset in normalisation by a factor of 10^{-4} . This supports the hypothesis that the parent population of quasars is identical to the general population of early-type field galaxies.

1. Introduction

Identifying the parent population of QSO host galaxies is one of the fundamental problems linking the QSO phenomenon to galaxy evolution in general. While the most widely adopted approach is to compare morphological (and increasingly also spectral) properties of normal and active galaxies, we investigate here the statistical distribution of galaxy luminosities. This short report highlights some results which will be elaborated in more detail in a series of forthcoming papers. We adopt $h = 0.5$ and $q_0 = 0.5$ throughout.

2. H band imaging of a complete QSO sample

In order to constrain the overall luminosity distribution of QSO hosts, the investigated targets must represent a *fair sample* of the QSO population. To obtain also the normalisation, the sample has furthermore to be *complete* (in the sense of comprising all QSOs within a given area that are brighter than a well-defined flux limit). Our sample has been selected from the Hamburg/ESO bright quasar survey (Wisotzki et al. 2000), with the following additional criteria: Right ascension between 9^{h} and 16^{h} ; nuclear absolute magnitudes $M_{B_J} < -23$; and redshifts $z < 0.3$. The resulting sample consisted of 30 targets distributed over 2200 deg^2 , all of which were subsequently observed. Because of the op-

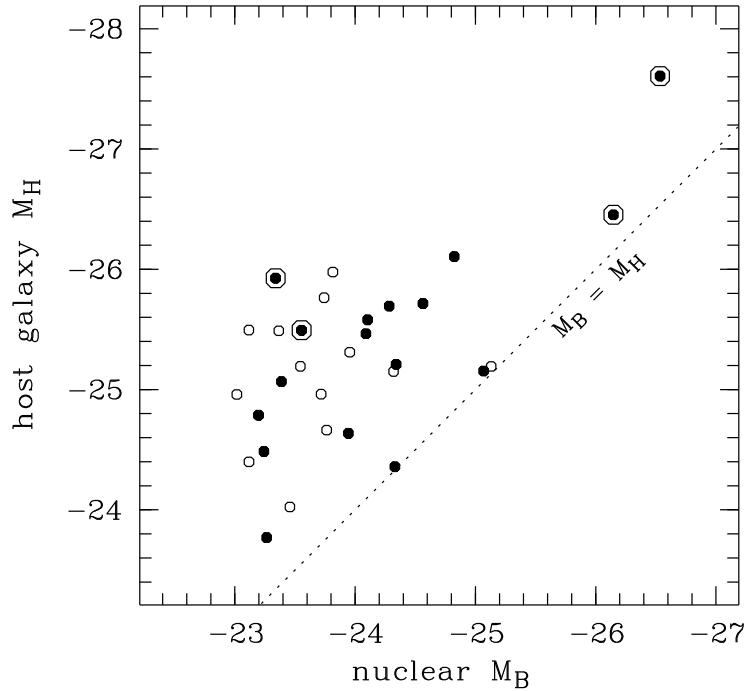


Figure 1. Host galaxy versus nuclear absolute magnitudes. Open symbols: disk-dominated hosts; filled dots: elliptical hosts. The four radio-loud QSOs are marked as circled dots.

tical selection, the sample is predominantly radio-quiet, containing only four bona fide radio-loud quasars.

Observations were conducted in February 1999 with the ESO NTT and its near-infrared camera SOFI. With a seeing between $0''.5$ and $0''.8$, the host galaxy was clearly detected in all cases, and after PSF subtraction, unique morphological type assignment was possible for most objects. A summary of the results:

- A disk model is preferred in 11 objects (37 %); there is often evidence for an additional substantial bulge component.
- A spheroidal model is preferred in 16 objects (53 %); for the QSOs with $M_{B_J} < -24$, 10 out of 12 (83 %) are spheroidal.
- Only three systems (10 %) are strongly interacting or irregular.
- All hosts are very luminous, $M_H \lesssim M_H^*$ with $M_H \simeq -24.5$ being a typical value for the general galaxy population (cf. below).

- There are no hosts with $M_{H,\text{gal}} > M_{B,\text{nuc}}$, thus the McLeod et al. (1999) diagonal boundary is confirmed and reinforced (in particular, there are no more upper limits).
- Except for this boundary, there is no convincing evidence for any correlation of $M_{H,\text{gal}}$ with $M_{B,\text{nuc}}$ (apart from the two extreme outliers 3C 273 and PKS 1302–102, which however are flat-spectrum radio sources and probably beamed).

3. Bivariate luminosity function

In order to fully describe a QSO host galaxy luminosity function (QHGLF), at least two independent variables are required: Host galaxy luminosity L_{gal} and nuclear luminosity L_{nuc} , leading to a *bivariate* luminosity function $\Phi(L_{\text{gal}}, L_{\text{nuc}})$. Cosmological evolution of the QSO population demands Φ to depend additionally on redshift z .

From the above results, we simplify the expression by tentatively assuming that QSO and host galaxy LFs are formally uncorrelated over the luminosity range of the sample under consideration.

$$\Phi = \phi(L_{\text{nuc}}, z) \psi(L_{\text{gal}}, z).$$

We adopt common parametric forms for both ϕ and ψ . The former can be well approximated, for low redshifts and not too low luminosities, by a single power law (Köhler et al. 1997; Wisotzki 2000), the latter is usually expressed by a Schechter function. For the evolution we assume a simple power-law form of pure number evolution, which is perfectly sufficient at low redshifts. The resulting expression for the QHGLF is

$$\Phi = \Phi_0 (1+z)^\kappa \left(\frac{L_{\text{nuc}}}{L_{\text{nuc}}^*} \right)^\alpha \left(\frac{L_{\text{gal}}}{L_{\text{gal}}^*} \right)^\beta e^{-L_{\text{gal}}/L_{\text{gal}}^*}.$$

An important additional feature is the McLeod et al. (1999) boundary, which basically states that for a given host galaxy mass (and hence luminosity), there is a well-defined maximum nuclear luminosity, essentially given by the Eddington limit of the central black hole. Although the universal validity of this boundary has recently been questioned by Percival et al. (2000; also these proceedings), it is clearly present in our data. We therefore decided to incorporate it by multiplying the above expression by a factor $\mathcal{H}(L_{\text{gal}} - xL_{\text{nuc}})$ where $\mathcal{H}(t_1 - t_2) = 1$ for $t_1 > t_2$ and 0 elsewhere is the Heavyside step function, and x is an adjustable parameter. For L_{gal} measured in the H band and L_{nuc} measured in B , we adopt $x \approx 1$ (this corresponds to the diagonal dotted line in Fig. 1).

Numerical values of the QHGLF parameters have been estimated by maximum likelihood fitting of the above functional form to the observed

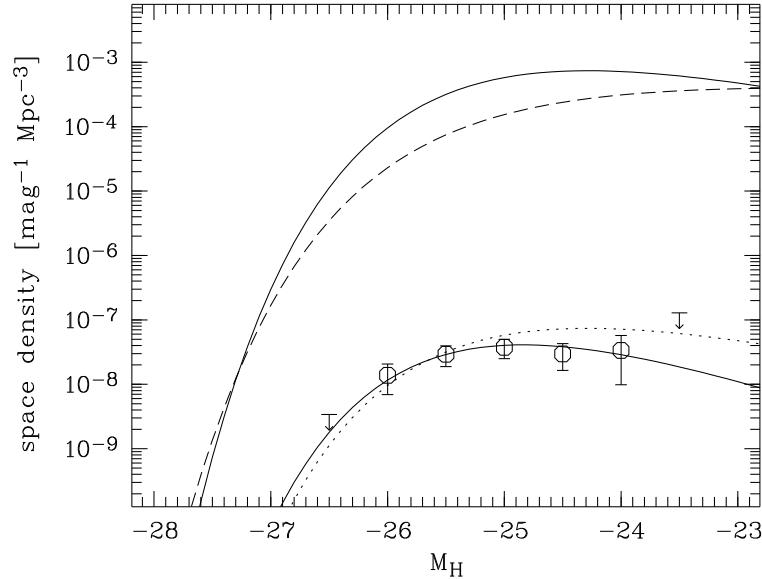


Figure 2. Estimates of the QSO host galaxy luminosity function. The points give the binned QHGLF with errors and upper limits from Poisson statistics. The lower solid curve is the best-fit maximum likelihood estimate. Also shown are some LFs of early-type field galaxies for comparison. Upper solid curve: Lin et al. (1999); dashed curve: Kochanek et al. (2001). The dotted line is the Lin et al. LF with rescaled normalisation to approximately match the QSO data points.

distribution of sources in $(M_{B,\text{nuc}}, M_{H,\text{gal}}, z)$ space. The resulting best-fit values are

$$\begin{aligned}
 \Phi_0 &= 1.3 \times 10^{-7} \text{ Mpc}^{-3} \quad \text{for } M_{B,Q}^* = -23 \\
 \kappa &= 6.5 \\
 \alpha &= -2.8 \\
 M_{H,\text{gal}}^* &= -24.6 \pm 0.3 \\
 \beta &= 0.5 \pm 0.5
 \end{aligned}$$

We have also determined binned estimates of the QHGLF under the assumption that the QSO luminosity function term $\phi(L_{\text{nuc}}, z)$ is well-described by the above parameters. The resulting binned and maximum likelihood estimates are shown in Fig. 2.

The last two parameters are particularly interesting, as they describe the *shape* of the galaxy luminosity function. In Fig. 3 we show confidence contours for these parameters and compare them with published values determined for the general field galaxy population (adapted to the *H* band by assuming typical galaxy colours). The characteristic luminosity

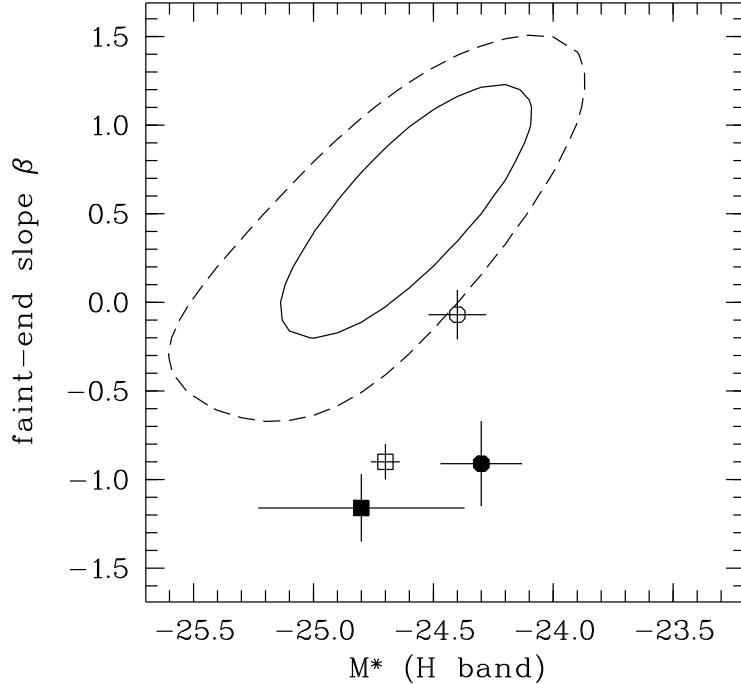


Figure 3. Likelihood contours for the HGLF parameters: The solid line corresponds to 68 %, the dashed line to 90 % confidence. Comparison values for the field galaxy LF are given by symbol markers. Open circle: Lin et al. (1999); filled circle: Gardner et al. (1997); open square: Kochanek et al. (2001); filled square: Loveday et al. (2000).

$M_{H,\text{gal}}^*$ is completely within the range found for field galaxies, while the faint-end slope β is only slightly flatter. The latter makes the QHGLF formally inconsistent with that of field galaxies, but Fig. 2 shows that the discrepancy even at the faint end is not large: The dotted line represents the Lin et al. (1999) LF of early-type field galaxies, rescaled to approximately match the normalisation of the QHGLF data points. The overall agreement is surprisingly good, and the slight mismatch at the faint end might even be explained by our limitation to only luminous QSOs.

To summarise, our results present no evidence that QSO host galaxies show a luminosity distribution widely different from that of inactive field galaxies. This lends considerable support to the hypothesis that the parent population of quasars consists of ordinary early-type galaxies, with very little if any bias towards higher luminosities or higher degree of morphological irregularities.

4. Implications for the QSO duty cycle

Dividing the space density of quasar hosts by that of the parent galaxies gives the ratio of active to inactive galaxies as a function of galaxy luminosity. This ratio has been interpreted in the past as the ‘probability’ of finding a QSO in a galaxy. By assuming that all major galaxies have massive black holes in their centres and using the argument of ‘ensemble average equals time average’, this is furthermore the *time fraction* that a typical galaxy spends in a ‘quasar state’ (also called the QSO duty cycle δ).

From our determination of the QHGLF, we found that the parent population can be probably identified with normal early-type field galaxies. Under these premises, we can estimate δ directly from the rescaling factor used in Fig. 2 to match the field galaxy LF to the QSO data points, giving $\delta \sim 10^{-4}$. Because of the similarity between the luminosity functions, there is virtually no trend of δ with luminosity. We can confidently exclude that the number density ratio between quasar hosts and luminous field galaxies approaches unity (implying $\delta \simeq 1$) as suggested recently by Hamilton et al. (2001).

Note that the above value for δ refers to zero redshift, since because of the explicit evolution term for the QSO space density in the analytic expression for Φ , the QHGLF normalisation is taken at $z = 0$. In this simple picture, QSO evolution would be interpreted as an increase in the duty cycle towards higher redshift with a rate of $\delta \propto (1 + z)^{6.5}$.

With $0 < z < 0.3$ for our sample, this corresponds to a time span of $T \sim 5$ Gyrs. Multiplying this with the redshift-averaged value of $\delta(z)$, we can convert the duty cycle into a time scale of $\langle \Delta t \rangle \simeq 10^6$ yrs, which is a robust lower limit to the total time a typical low-redshift quasar is switched on, and probably not too different from the actual time scale for quasar-type activity.

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